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Study of outcome of steel slag inclusion on properties of silica fume blended cement concrete

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Abstract: As we realize that there are numerous quantities of by-products like, steel slag, silica fume, fly ash, etc, and so forth that are created amid the generation or the assembling of material like steel, silicon metal, and so on as a waste material. In India, the creation of steel slag is around 12 million tons in the steel enterprises and we can use in our solid as a useful supplementary cementetious material. Cement is most normally and generally utilized building material utilized as a part of all around the globe. Concrete is the mixture of cement, sand, aggregates (fine and coarse), and water. The use of cement is ceaselessly expanding because of which there is an incredible impact on natural resources. For lessening this significant issue, we ought to take the materials that can substitute the characteristic assets. In this way, we are going to utilize Steel slag and silica fume which is a modern by product acquired after the generation of steel and silicon metal individually.

The production of steel is connected with the liberation of solid waste materials like slag. The generation of solid waste material is around 29 million tons every year. In fact, numerous by items and solid squanders can be utilized as a part of cement blends as aggregates, sand and cement substitution, contingent upon their compound and physical portrayal, if enough treated. In steel industry, steel slag having attractive qualities and can be utilized as coarse aggregates and additionally fine aggregates in concrete development.

The fundamental ability of slag is to refine the steel and to assimilate the oxides which are shaped as an after effect of de-oxidation amid steel generation. Silica fume is a side product of delivering silicon metal or ferro silicon composites and it is otherwise called Micro silica or miniaturized scale silica. A standout among the most helpful uses for silica smoke is in cement due to its substance and physical properties; it is an exceptionally reactive pozzolana. Concrete containing silica smoke can have high quality and can be exceptionally strong along with durability. Use of these kinds of supplementary materials decreases the ecological contamination as they are all the waste products of liberation of some major compound in addition they improve the properties of the material like concrete in fresh and hydrated state. The properties of concrete like strength, durability and so on predominantly rely on the nature of the material utilized as a part of undertaken project. To examine the the quality of concrete for design configuration reason the compressive quality and flexural quality are the two essential attributes. Along these lines, in my task work utilized 4 diverse rates of steel slag with consistent rate of silica fume as a supplementary material with fine aggregate and bonding material (cement) respectively. The different rates of steel slag are 40%, 45%, 50% and 55% and while consistent rate of silica fume is 10%. The consistent rate in silica fume in light of the fact that from past undertakings through different studies that at 10% of supplanting of silica fume with cement gives best result. In the undertaking we decide the impact of silica fume on the steel slag concrete.

Introduction

The rapid growth in industry has resulted in large amount waste materials being generated from industry which can be used as Supplementary Cementations materials. A fewer materials to enlist are bagasse fly ash, silica fume, GGBS, steel slag etc. The use of such waste products not only relaxes economy in construction but also modifies the concrete properties in the two states that is fresh and hardened. Slag cement and fly ash are amongst the general SCMs used in manufacturing concrete now a day. The concrete produced in current period includes one or both of these materials. The various researches reveal that the most successful SCM is silica fume because it enhances the strength as well as durability characteristics of concrete to much greater consequently attracting the construction, designing an research industry to prefer silica fume for excelling concretes. Good quality aggregates also play a vital in production of superior quality concrete. Steel slag being industrial byproduct/waste material acquired from the steel manufacturing industry and same can be used as aggregate in fines or coarser form in concrete. It is currently used as aggregate in hot mix asphalt surface applications, but can also be used for other construction aspects so that industrial byproduct can be efficiently disposed to serve advantageous purposes rather than creating environmental problem. Steel slag aggregates can be used as replacement for coarse and fine aggregates to specific percentages to get desirable results.

Silica Fume

Silica fume, also known as micro-silica, is a (non-crystalline) polymorph of silicon dioxide. It is an ultrafine powder gathered as a by-result of the silicon and ferrosilicon amalgam creation and comprises of spherical particles with a normal diameter of molecule equal to 150 nm. The fundamental field of use of silica fume is as pozzolanic material for superior concrete.

Silica fume is an superfine material with circular particles under 1 μm in diameter, average around 0.15 micron meter. This makes the silica fume about 100 times finer than the normal particles of concrete. The bulk density of silica fume depends on the degree of densification in the silo and varies from 130 kg per cubic meter to 600 kg per cubic meter. The specific gravity of silica fume ranges from 2.2 to 2.3. The specific surface area of silica fume generally ranges from 15,000 sq meters per kg to 30,000 sq meters per kg.

Advantages of using Silica Fume

The use of silica fume gives wide range of benefits besides cost reduction. It can be used for precast and in-situ concrete.

SF has specific benefits during construction:

1. Cohesiveness of fresh concrete improves consequently leading improved handling properties.
2. Curing can be started start earlier as there is no need to wait for bleed water to dissipate.
3. Silica fume results in high early strength of concrete.

There are significant improvements in concrete consisting of silica fume in terms of mechanical performance and resistance to chemicals (such as acids, fuel oil, chlorides and sulfates) because of dense microstructure of concrete consisting of silica fume.

Characteristics of hardened *silica fume* concrete include:

a. Less permeability and improvement in durability.
b. Development of greater resistance against abrasion and impact than conventional concretes of similar strength grade.
c. Greater flexural strength and modulus of elasticity as compared to concretes of equal compressive strength.
d. Better resistive attributes against explosive spalling during exposure to fire.

Steel Slag

Steel slag is obtained as by product in steel making process, is delivered amid the separation of steel in molten state from impurities in steel furnaces. This can be utilized as aggregate (coarse or fine) in concrete.

Steel slag now a days is commonly as aggregate in hot mix asphalt surface applications, but some research work is required to determine the feasibility of utilizing slag more wisely as a replacement for both fine and coarse aggregates in a conventional concrete mixture so as to benefit economic and environmental footprints and overcome the non availability of raw materials. Concrete is mainly composed of aggregates in terms volume and fine aggregates form a considerable amount of it. Replacing fine aggregates in some specific percentages with steel slag aggregate (Fine) can lead to appreciable environmental benefits. Steel slag has high specific gravity, high abrasion value than naturally available aggregate.

Literature Review

Researchers have done a wide variety of work in context to introducing supplementary cementations materials and replacing natural aggregates with byproducts obtained as industrial waste during production principal material.

The literature work framed by researchers has been drastically used for production of building materials of better quality and reduced cost. The innovations in concrete have also offered more research area in terms of search for variety of materials that can be used as replacements for cements and aggregates. Some of the research works are discussed herewith this report.

Material used:

Cement

In this research, 43 grade Ordinary Portland cement conforming to IS: 8112 – 1989 is used. The greenish gray in color, it felt cold when hand was dipped in cement bag, no lumps were found. The physical and chemical properties of cement are summarized in table below

Physical and chemical Properties of Cement

Parameter	Value
Fineness (sieving by 90 µ sieve)	97% passed
Specific gravity of cement	3.15
Soundness obtained by Le- Chatellier's Apparatus	3 mm
Standard consistency obtained by Vicat's apparatus	36 %
Initial Setting time	30 minutes
Final Setting time	610 minutes

Fine aggregates

The fine aggregates of size less than 4.75 mm were used. The various properties are given in Tables as summarized below:

Properties of Fine Aggregates

Parameter	Value
Specific Gravity	2.58
Water absorption of fine aggregate	1%
Free surface moisture of fine aggregate	0%
Colour	Gray
Bulk Density	1669 kg/m^3

Sieve Analysis of Fine Aggregates (Confirming IS: 1067 – 1962)

S. No	IS sieve size	Weight of retained (kg)	Percentage weight retained	Percentage weight passing	Cumulative percentage weight retained
1	10 mm	0.00	0.00	100	0.00
2	4.75mm	0.012	0.60	99.40	0.60
3	2.36mm	0.020	1.00	98.40	1.60
4	1.18mm	0.061	3.05	95.95	4.65
5	600micron	0.420	21.00	74.35	25.65
6	300micron	1.392	69.60	4.75	95.25
7	150micron	0.071	3.55	1.20	98.80

Total cumulative percentage (F) = 326.55

Calculation:-
Fineness modulus of fine aggregate:

$$\frac{(\textbf{Total cumulative percentage (F)} = \textbf{326.55})}{\textbf{100}}$$

Result:-The fineness modulus of fine aggregate= 3.27

Coarse aggregates

The aggregates having size greater than 4.75 mm called as coarse aggregates. The coarse aggregates having size 20 mm used. The shape of the coarse aggregates was angular. The properties of coarse aggregates are summarized below:

Parameter	**Value**
Specific Gravity	2.69
Water absorption of coarse aggregate	0.50 %
Free surface moisture of coarse aggregate	2 %
Colour	Gray

Sieve Analysis of Course Aggregates (Confirming IS: 10067 – 1962)

S. No	IS sieve size	Weight of retained (kg)	Percentage weight retained	Percentage weight passing	Cumulative percentage weight retained
1	80mm	0	0	100	0
2	40mm	0	0	100	0
3	20mm	0.092	1.84	98.16	1.84
4	10mm	4.676	93.52	4.64	95.35
5	4.75mm	0.092	1.84	2.8	97.20
6	Residue	0.140	2.8	0	100

Total cumulative percentage (C) = 294.4%
Calculation:-
Fineness modulus of course aggregate: 500

$$\frac{(\mathbf{C} + \mathbf{500})}{\mathbf{100}}$$

Result:-The fineness modulus of coarse aggregate= 7.94

Aggregate Impact Value (confirming IS: 2386 (Part IV) – 1963)

Sr. No.	Sample No.	W1 (Kg)	W2 (Kg)	W (Kg)	W3 (Kg)	Impact value (%age)
1.	A	0.837	1.204	0.367	0.045	12.26
2.	B	0.837	1.190	0.353	0.046	13.03
3.	C	0.837	1.193	0.356	0.048	13.76

$$\text{Average impact value of aggregates} = \frac{(12.26+13.03+13.76)}{3} = 13.02\ \%$$

Aggregates Crushing Value (confirming IS: 2386 (Part IV) – 1963)

Sr. No.	Weight of an empty mould (W1) kg	Wt. of agg. with mould (W2) in Kg	Total wt. of aggregates W = W2 – W1	Wt. of material passing from 2.36mm sieve size	Aggregate crushing value = W3/W x100
1.	13.648	16.486	2.838	0.492	17.33 %
2.	13.648	16.444	2.796	0.495	17.70 %

3.	13.648	16.427	2.779	0.486	17.49 %

Average value of crushing of the aggregates = 1 7 . 3 3 + 17.70 + 17.49 = 17.51 %

Silica Fume

Silica fume is obtained as a byproduct while production of silicon metal and ferrosilicon alloys. Silica fume due to its properties is an excellent replacement of cement to a specific percentage. Its physical and chemical properties make it an excellent pazzolana. Silica fume impregnated concrete can exhibit high strength and durability. Silica-fume concrete requires special attention while placing, finishing, and curing.

The raw materials such as quartz, woodchips and coal are used to produce silicon metal and in electric furnaces. The byproduct that is obtained from furnace is collected as silica fume.

Silica fume mainly comprises of amorphous (non-crystalline) silicon dioxide (SiO^2). The silica fume particles are ultrafine, approximately 1/100th the size of an average cement particle. As a result of its ultrafine particles, considerable surface area, and the high value SiO^2, silica fume is a highly reactive pozzolanic material, when added to concrete.

Silica fume is available in wet and dry forms. The silica fume is introduced during production of concrete at a concrete plant. Cements blended with silica fume are also available in market with different grades Silica fume is an extremely fine material consisting of spherical particles less than 1 µm. The specific gravity of silica fume varies within the range of 2.2 to 2.3. The bulk density varies from 130 (undensified) to 600 kg/m^3. The specific surface area of silica fume ranges from 15,000 to 30,000 m^2/kg.

Table 3.8 Chemical and Physical Characteristics of Silica Fume

Parameter	**Value**
Silicon Dioxide percentage	85-97 %
Calcium Oxide percentage	Less than 1 %
Specific Surface in square meter per kg	15000-30000
Specific Gravity	2.22

Steel Slag

Steel slag is an industrial bi-product produced during the production of steel and is considered as an environment hazard if not recycled or disposed safely. Steel slag may be used as a building material by converting it into fine and coarse aggregates. The aggregates formed can have a wide variety of application in building and highway domain.

In this work, Steel slag is used as replacement for sand (fine aggregates), and its results are revealed in the later sections. Fundamentally, steel on a very basic level is a composite of iron and carbon containing up to 2% carbon and 1% manganese and minute quantities of Silicon, Phosphorus, Sulfur and Oxygen.

Besides being used for Civil Engineering applications steel is also the world's most fundamental constituent in other Engineering domains consequently leading to increase its demand. In the domain of Civil Engineering the applications of steel can be observed everywhere, for instance, steel bars, edges, channels, bends, trusses, steel tanks and much more. The steel slag used for the study is Electric Arc Furnace Slag and is used as replacement of fine aggregates

Water

The specifications for water used in the laboratory were well met as per provisions given by Indian Standard 456. The water was free from any kind of impurities, grease, oils and it had clear transparent appearance.

Results:

In this chapter the various tests performed on concrete and their results have been discussed in detail. The comparisons have been depicted analytically through tables.

Slump test

Slump test was observed on concrete with standard case and different replacements and results are summarized in the table below

Mix Type	Replacement details of cement with silica fume	Replacement details of sand with steel slag	Slump observed (mm)
Standard Concrete Composition (SCC)	10% by weight	0% by weight	68
Content replacement 40 (CR45)	10% by weight	40% by weight	66
Content replacement 45 (CR45)	10% by weight	45% by weight	64
Content replacement 50 (CR50)	10% by weight	50% by weight	62
Content replacement 55 (CR55)	10% by weight	55% by weight	59

The above test results implies that workability of fresh concrete decreases upon addition of steel slag and its increment through replacement against sand used in manufacturing concrete.

Compaction factor test

Mix Type	Replacement details of cement with silica fume	Replacement details of sand with steel slag	Compaction factor
Standard Concrete Composition (SCC)	10% by weight	0% by weight	0.90
Content replacement 40 (CR45)	10% by weight	40% by weight	0.85
Content replacement 45 (CR45)	10% by weight	45% by weight	0.83
Content replacement 50 (CR50)	10% by weight	50% by weight	0.83
Content replacement 55 (CR55)	10% by weight	55% by weight	0.82

The test results show that the compaction factor of fresh concrete decreases upon addition of steel slag and its increment through replacement against sand used in manufacturing concrete. The results hold good to indentify concrete manufactured using steel slag and silica fume as ok in context to its fresh state

Compressive strength test

Mix Designation	Replacement details of cement with silica fume	Replacement details of sand with steel slag	7 days Average Compressive Strength in N/mm^2	28 days Average Compressive Strength in N/mm^2
Standard Concrete Composition (SCC)	10% by weight	0% by weight	17.377	32.31
Content replacement 40 (CR45)	10% by weight	40% by weight	18.36	30.65
Content replacement 45 (CR45)	10% by weight	45% by weight	19.64	32.72
Content replacement 50 (CR50)	10% by weight	50% by weight	20.94	33.29
Content replacement 55 (CR55)	10% by weight	55% by weight	12.32	24.36

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The 7days and 28 days compressive strength test results as above predict that results hold good for sand replacement with steel slag to range of replacement of 40% to 50% where as it decreases abruptly on 55% replacement.

The maximum values are obtained on 50% replacement of sand with steel slag. The above test results as conclusion offer an idea of replacing sand with steel slag to a range of 40% to 50%. The best results are obtained on 50% replacement.

Flexural strength test

Mix Designation	Replacement details of cement with silica fume	Replacement details of sand with steel slag	7 days Average Flexural Strength in N/mm^2	28 days Average Flexural Strength in N/mm^2
Standard Concrete Composition (SCC)	10% by weight	0% by weight	2.56	3.85
Content replacement 40 (CR45)	10% by weight	40% by weight	3.07	3.91
Content replacement 45 (CR45)	10% by weight	45% by weight	3.21	3.95
Content replacement 50 (CR50)	10% by weight	50% by weight	3.59	4.31
Content replacement 55 (CR55)	10% by weight	55% by weight	3.72	4.45

The flexural strength results show that the flexural strength increases with increase percentage of steel slag in concrete but as optimum results are obtained at 50% replacement in context to compressive strength the absolute result for both can be said to be attained at 50%.

Split tensile strength test

Mix Designation	Replacement details of cement with silica fume	Replacement details of sand with steel slag	7 days Average Split tensile Strength in N/mm^2	28 days Average Split tensile Strength in N/mm^2
Standard Concrete Composition	10% by weight	0% by weight	2.32	4.55
Content replacement 40 (CR45)	10% by weight	40% by weight	2.12	4.32
Content replacement 45 (CR45)	10% by weight	45% by weight	1.99	4.10
Content replacement 50 (CR50)	10% by weight	50% by weight	1.81	3.90
Content replacement 55 (CR55)	10% by weight	55% by weight	1.67	2.99

Note: The formula used to calculate the above values of split tensile strength is

$$\frac{2P}{\pi \times d \times l}$$

P = max. Load in (N)
d = dia. of the specimen in mm
l = measured length in mm.
The results show that the split tensile strength decreases with increase of steel slag percentage in concrete and optimum results are obtained within 40% to 50%.

Discussion

The topic gives us a vast idea about the properties of steel slag and silica fume in the concrete and how it affects its properties by using different percentages of steel slag.

From the results obtained from compressive strength test results it is observed that compressive strength of concrete is obtained with optimum results at a replacement of 50% of sand with steel slag fine aggregate.

The flexural strength of concrete goes on increasing with increase in percentage of silica fume beyond 50% of total content.

The split tensile strength is observed maximum at 45% and is within limits unto 50% and from test results it is observed that split tensile strength decreases on 55% addition steel slag in place of concrete.

Out of four percentages i.e. 40% 45%, 50% and 55% replacement of silica fume and constant value of silica fume replacement i.e. 10%, the results show that the strength i.e. (compressive strength, flexural strength and tensile strength) will be optimum on 10% silica fume and 50% of steel slag replacement with cement and fine aggregates respectively.

Therefore 50% replacement of steel slag with the fine aggregates and 10% replacement of silica fume with cement give best result.

Conclusions

The conclusions made from the undertaken research study are enumerated below:

1. Silica fume can be used as a replacement of cement up to 10% as seen from the references used for conduct of current research program.
2. Addition of steel slag increases the compressive strength of concrete, the addition steel slag is very much favourable with a percentage of 50 but further additions lead to decline of compressive strength.
3. Steel slag can be used as replacement of fine aggregates doing a replacement of 50% with fine aggregates to get optimum results for compressive strength, flexural strength and split tensile strength as from the results obtained one can approach to results that at 50% addition results within standardised & optimised limits are acquired .
4. The use of steel slag and silica fume does effect the workability of concrete to considerable extent and the standards set for workability are achievable with addition of steel slag and silica fume
5. The replacement of cement with silica fume gives relaxation to cement industry and ultimately to the economical footprint of cement industry. The fast pace construction in modern era consequently leading increase in cement demand and further leading to increased prices of cement as well as raw material required for cement can be somehow relaxed by the use of supplementary cementitious material silica fume which proves good to be blended with concrete up to specified limits.
6. The replacement of steel slag fine aggregate will give a vide relaxation to economic footprint of aggregate industry as 50 percent of replacement can lead to reduction of cost of fine aggregates considerably even after its processing. The processing involves separating slag from the raw material obtained and grinding steel slag to proper grading. Being a waste product of steel industry slag will be very cheap.

The use steel slag and silica fume in concrete with their replacements with fine aggregate and cement also benefits the environmental foot prints. As both the materials are by products of industrial manufacturing they have to be dumped, leading to environmental degradation because of their toxic natures assimilated during industrial manufacturing processes.

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